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The Behavioural Rules of People During Disaster Emergency Evacuation: A Case Study of Mount Merapi Eruption in Indonesia

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Abstract: Good evacuation planning is a crucial factor in the success of the evacuation. A well-planned evacuation could save thousands of lives, property and social infrastructure. This is in line with the objective of humanitarian logistics which is designing and controlling an effective and efficient system in order to alleviate the suffering of disaster victims. A currently existing problem is that is a policy to determine evacuation routes during the eruption of Mount Merapi has not been implemented systematically and quantitatively, so that the policy to determine evacuation routes is considered ineffective and inefficient. A quantitative planning is regarded better because it is more measurable which involves in-depth analysis based on various scenarios obtained from computer simulations. The method used in this research was analyzing literature review of several previous studies. The results of such literature review produced a flow chart of behaviours that consisted of five types of Mount Merapi community behaviuor in facing disaster evacuation. The flowchart of behaviour served as the basis for designing the Agent-Based Modeling (ABM), a computer simulation model, in which the model is the interaction of complex adaptive system that focuses on bottom-up approach.

Key words: Framework, behavior, disaster evacuation, agent-based modeling, humanitarian logistics

INTRODUCTION

Indonesia has 130 active volcanoes, one of which is Mount Merapi. Mt. Merapi is located in the central part of Java Island, Indonesia. Administratively, it is located in two provinces, namely Central Java and Yogyakarta special region. Geographically, Mt. Merapi is located on 7 32.5' South latitude and 110 26.5' East longitude. Mt. Merapi is one of the most active volcanoes in Indonesia (Voight *et al*., 2000) and also in the world (Dove, 2008; Lavigne *et al*., 2008; Thouret *et al*., 2000). The last eruption of Mt. Merapi took place in October-November, 2010. The eruption of Mt. Merapi has caused loss of life, property and social infrastructure. It is recorded that the eruption of Mt. Merapi in 2010 made 61,154 people evacuated, 341 people died and 368 people seriously injured. In addition, 3,307 buildings were damaged, the losses were estimated at 4.23 trillion rupiahs.

Rescuing victims from natural disasters is a significant challenge to do, so that planning in an evacuation is crucial. A good evacuation planning is able to save thousands of existing lives and social infrastructure (Bohannon, 2005) and it can guarantee that victims can leave the danger zone so that the evacuation goes effectively.

During the evacuation from a natural disaster, people face a series of important decisions among others whether to evacuate when, to where and by the which mode. In the case of the disaster evacuation from the eruption of Mt. Merapi, the decision includes whether to go/stay and when, preparation of vehicle decision in selecting the evacuation routes (Yin *et al*., 2014).

In general, people living on the slope of Mt. Merapi face three phases of the evacuation decision (Phase 1) decision to go/stay and when (Phase 2) preparation of vehicle and (Phase 3) decision on evacuation route selection (Handayani *et al*., 2016). People's behavior is formed from a combination of various factors/attributes which will form the characteristics of behavior which result in different types of behavior. By combining the existing attributes there are five types of behavior of people living on the slope of Mt. Merapi, namely behavior of official leader, behavior of cultural leader, behavior of vulnerable groups, behavior of prepared community members and the behavior of unprepared community members (Handayani *et al*., 2016). Each type of behavior shows a series of different behavioral rules.

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Table 1: The comparison between DES, SD and ABM

Variables	Discrete Event System Simulation	System Dynamics	Agent-Based Modeling
Research focus	DES primarily investigates the performance over time of an interconnected system subject to internal and external random variability	SD primarily investigates the performance over time of an interconnected system arising from its internal feedback structure	ABM investigates the performance of an agent to the time connected to the system
Basic building block	Entity and attributes	Feedback loop	Agent
Level of modeling	Meso	Macro	Micro
Unit of analysis	Event	Structure	Rules
Perspective	Top-down	Top-down	Bottom-up
Adaptation	DES models are generally stochastic in nature. The randomness is generated through the use of statistical distributions	Change of domain structure in SD model, the structure has to be determined before starting the simulation	The change in structure can happen, for instance be achieved by the use of evolutionary or genetic algorithm
Handling of time	Discrete	Continuous	
	The state variable(s) change only at discrete set of points in time	SD focus lies on continuous policies in contrast to the focus on individual events in DES	In ABM proposition about the handling of time

Agent-based modeling is one of the computer simulation modellings used for simulating behavioral rules agent (North and Macal, 2007). The agent is people living on the slope Mt. Merapi with different behavioral rules. From the previous discussion, the behavioral rules of people living on the slope of Mt. Merapi are grouped into five types of behavior. This study is made to describe the behavioral rules performed by each type of behavior of people living on the slope of Mt. Merapi which are collected from previous studies.

MATERIALS AND METHODS

Humanitarian logistics is a branch of supply chain science, which discusses how to organize, deliver and store aid supplies during disasters which aims to alleviate the suffering of disaster victims, including the complexity of how to deal with emergencies during disasters, including the evacuation in emergencies (Tomasini and Wassenhove, 2009).

ABM is one of several simulation methods that can be employed, whose advantage is that it can save time, effort and cost compared to working in a real situation. The Agent-Based Modeling (ABM) is a modeling simulation that models a system. The system is modeled as a collection of autonomous decision-making entity, such collection of entity is called agent (Bonabeau, 2002; Macal and North, 2005).

In general, there are several simulation modeling that can be employed to model a disaster simulation such as Discrete Event System Simulation (DES), System Dynamics (SD) and Agent-Based Modeling (ABM). Borshchev and Filippov (2004) and Maidstone (2012) compare three methods in simulation modeling approaches, namely Discrete Event System Simulation, System Dynamics and Agent-Based Modeling. The comparison emphasized on research focus, basic building block, level of modeling, unit of analysis, perspective, adaptation and handling of time.

Cellular Automata (CA) is a simple form of Agent-Based Modeling (ABM) which has many similarities with ABM. However, behavioral rules in CA are limited to movement only, not to other features. The comparison between methods is described in Table 1.

This study is a result of literature search about behavior of people living on the slope of Mt. Merapi while they were evacuated from the eruption. Papers showing the behavior during the evacuation from Mt. Merapi were collected until the eruption of Mt. Merapi in October-November, 2010. Key words used in searching literature were “disaster” (or) “perception” (or) “behavior” (or) “volcano” (or) Indonesia and “Merapi”. Academic articles were obtained using Google scholar until 2016. Behavioral rules from the results of this research were then simulated using one of the platforms of agent-based modeling conducted in the further research (Donovan, 2010; Dove, 2008; Lavigne *et al*., 2008; Mei and Lavigne, 2012; Mei *et al*., 2013; Pan, 2006).

RESULTS AND DISCUSSION

Figure 1 until Fig. 5 in this study describe the behavioral rules of people living on the slope of Mt. Merapi during the emergency evacuation from the eruption Mt. Merapi. Figure 1 describes the behavioral rules of official leader, Fig. 2 describes the behavioral rules of cultural leader, Fig. 3 describes the behavioral rules of vulnerable group, Fig. 4 describes the behavioral rules of prepared community members and Fig. 5 describes the behavioral rules for unprepared community members.

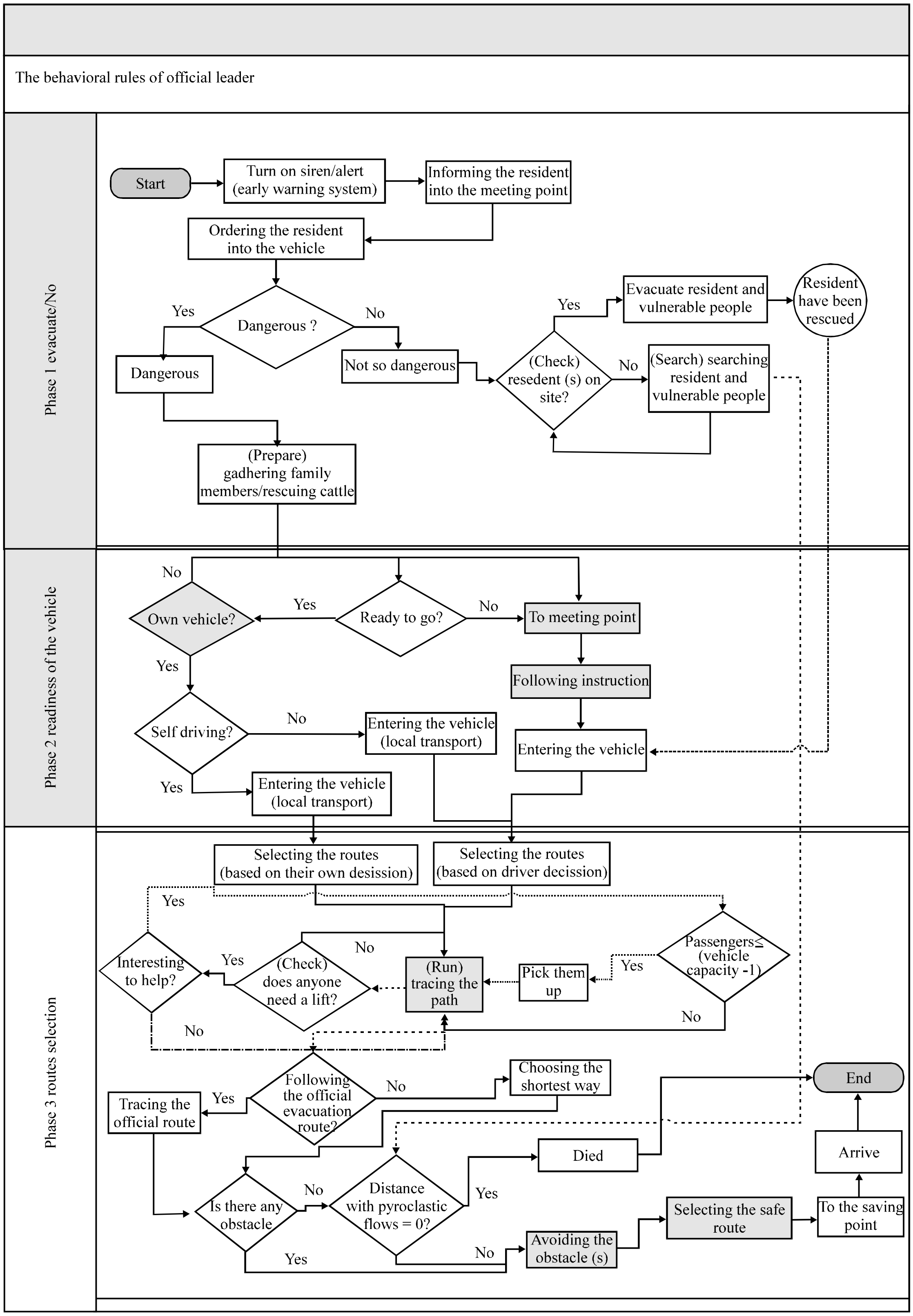

Fig. 1: Behavioral rules of official leader

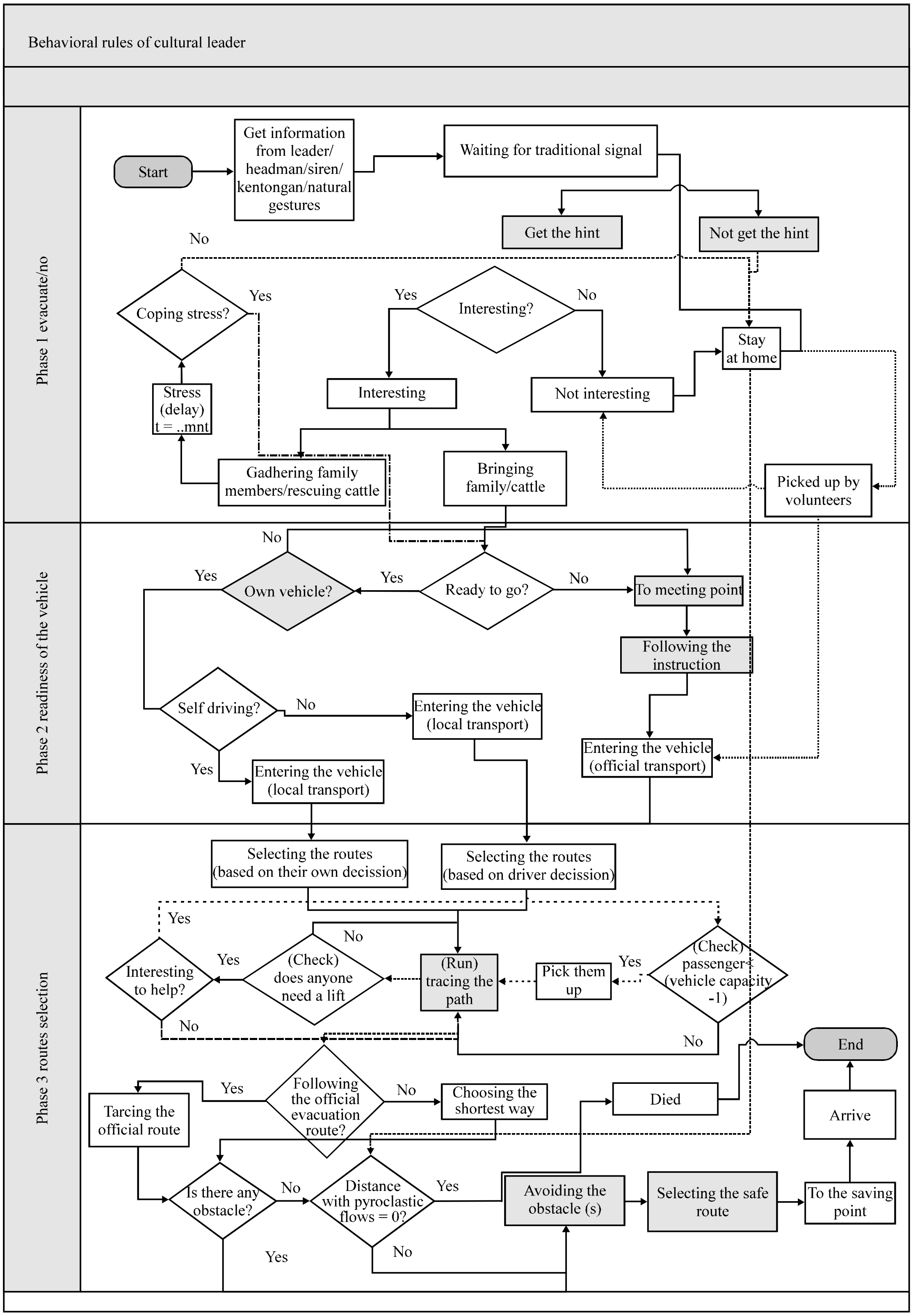

Fig. 2: Behavioral rules of cultural leader

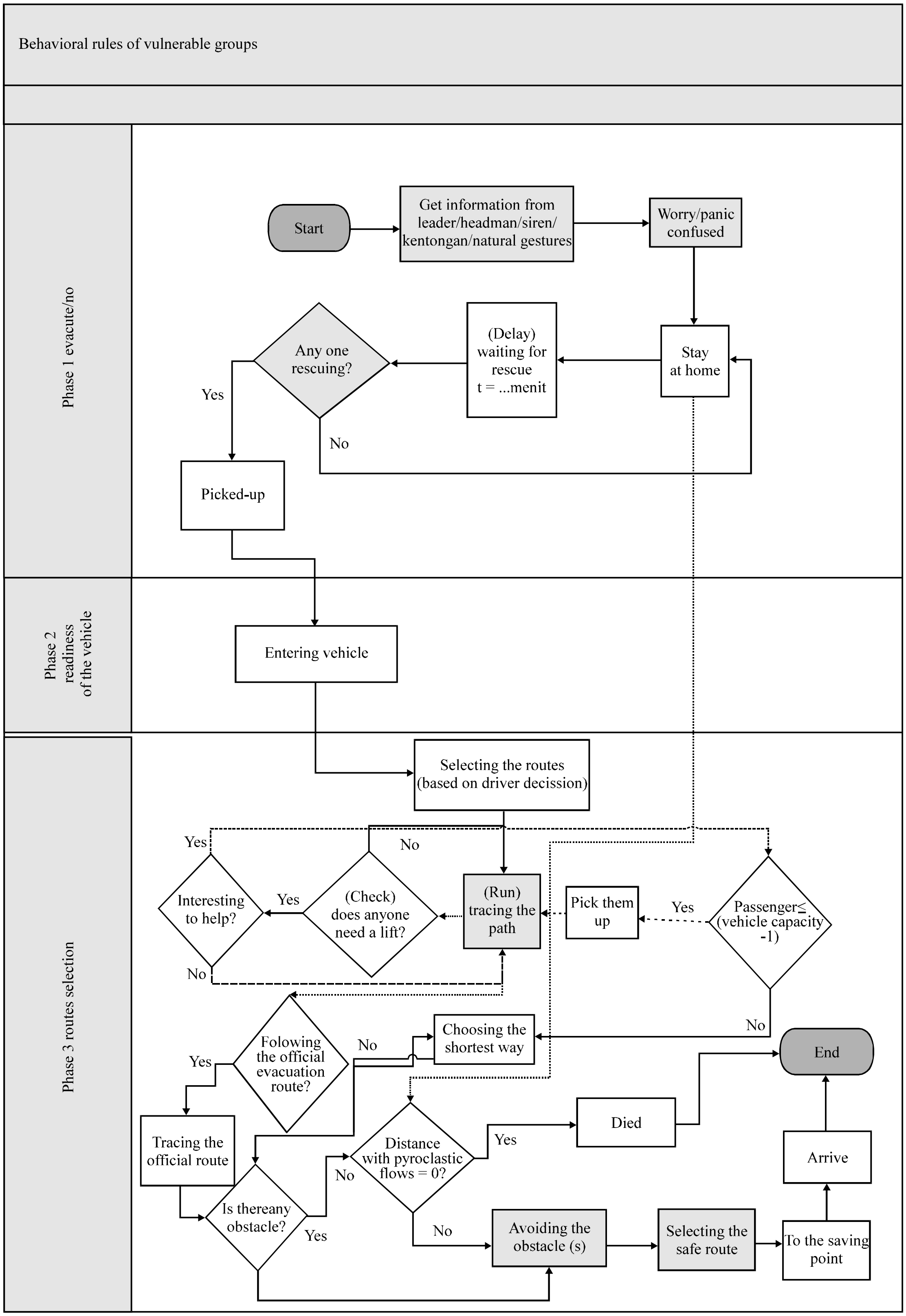

Fig. 3: Behavioral rules of vulnerable groups

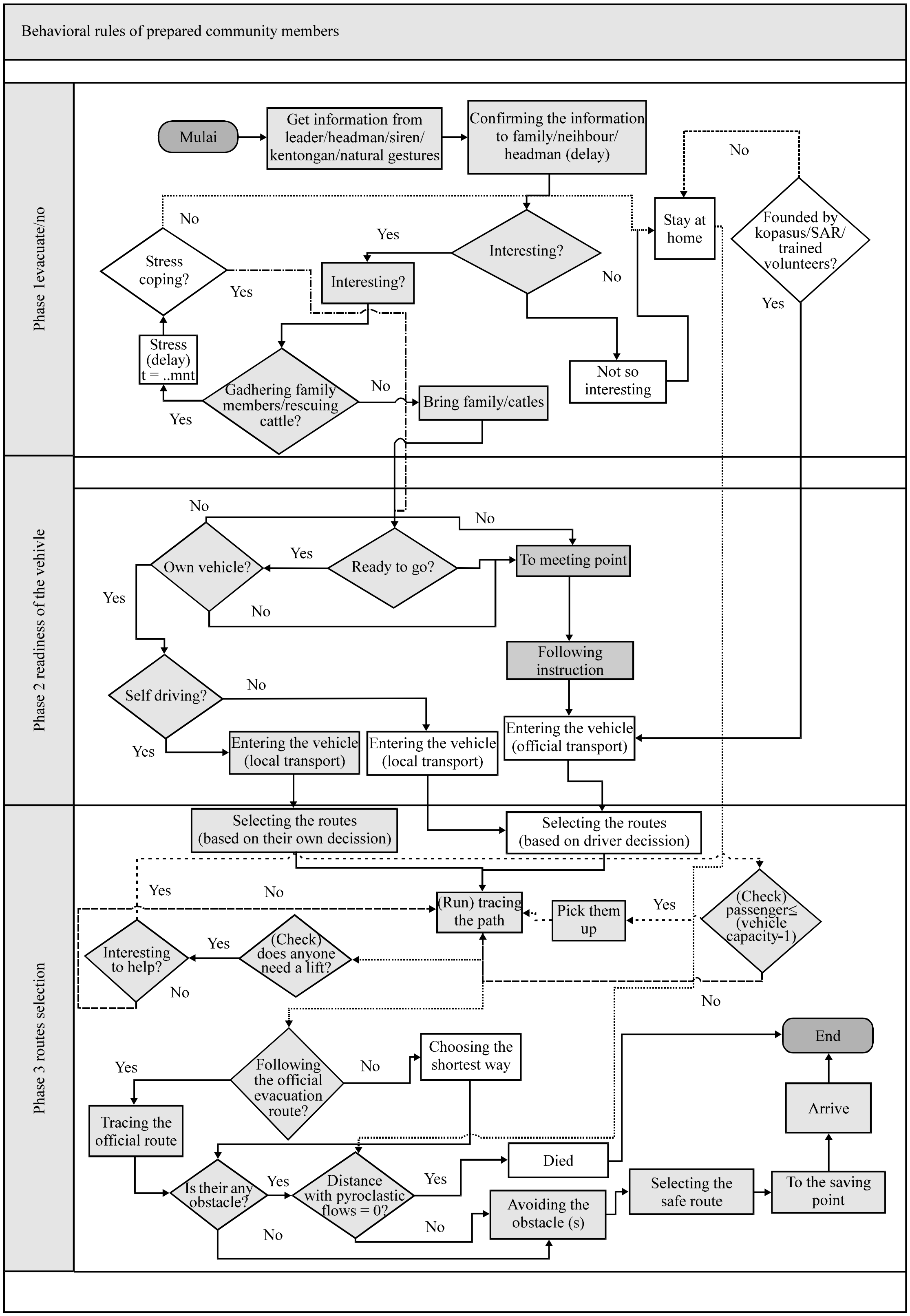

Fig. 4: Behavioral rules of prepared community members

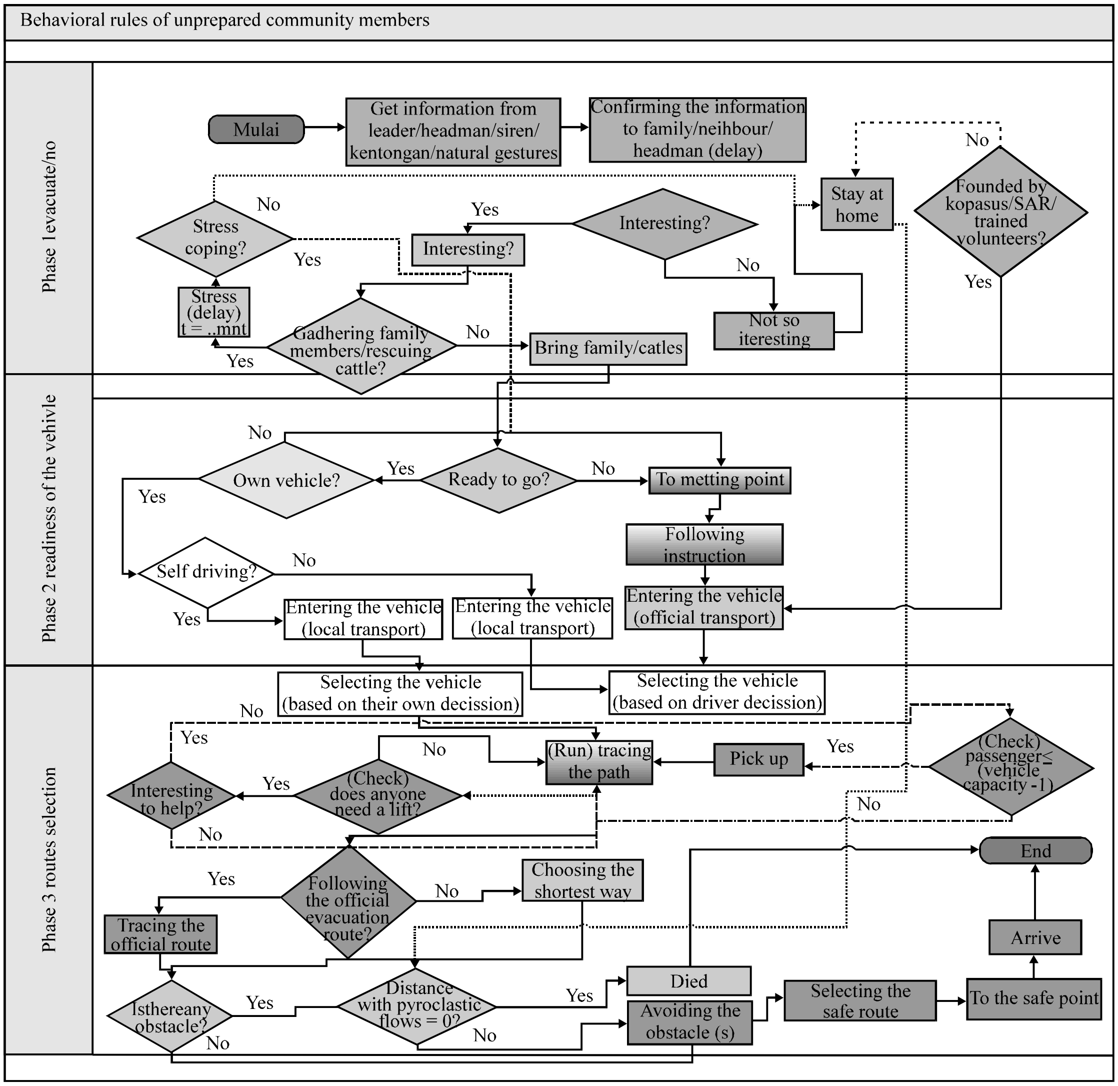

Fig. 5: Behavioral rules of unprepared community members

Prepared community members are groups of people that are deemed prepared in all phases of the decision making. This type is characterized by being rational, being able to manage stress, abiding by government regulation, prioritizing self safety having prepared vehicles and knowing evacuation routes. If they indicate unpreparedness at least in one of the phases they will be classified into unprepared behavior.

The type of leader behavior has characteristics similar to prepared community members. The difference is that the type of leader has the ability to direct others and spread information to others. It consists of official leader and non-official leader. The difference between both types lies in rationality in managing information and making decisions which are influenced by culture and beliefs. The type of non-official leader tends to believe in mystical instructions from ancestral spirit while the type official of leader is more rational and follows rules and information from government and scientists.

The last type of behavior is vulnerable groups. Vulnerable means people with disabilities who depend on the help of others, vulnerable groups consist of pregnant women, children the elderly, individuals with disabilities and injuries.

However, one can exhibit adaptive or non-adaptive behavior. Adaptive behavior is behavior which changes due to certain conditions such changes occur because of cognitive processes which are affected by three factors: physical, psychological and environtmental factor (Pan, 2006). Physical factor is affected by dimensions of the body, mobility, age and gender.

Psychological factor is divided into three groups: Individual, affected by instinct, experience and bounded rationality. Interaction among individuals which is established due to social structure, personal space and principle of social proof. Non-adaptive behavior often appears in a group of people with high levels of individualism and non-social attitudes. The consistency of an individual with their social identity depends on their levels of stress and tolerance. And interaction of individual with groups. Crowd density can also affect the psychological factor.

The third factor is environtmental characteristic factor that divided into geometric constraints, emergencies and emergency egress systems and also in this research there is another factor that can affect individuals in exhibiting adaptive/non-adaptive behavior, namely perspective factor. This factor appears due to adaptive plan which is developed from the experience of facing disaster, individual definitions of the threat and the level perceived of hazard.

CONCLUSION

A good planning is required to achieve the success of disaster evacuation. It will certainly help in the formulation of an effective policy. One of the efforts in formulating the policy on the selection of evacuation routes is by involving factors that affect evacuation system such as environment, types of disasters and people's behavior. People's behavior is formed by a combination of various factors/attributes. Such combination will form the characteristics of behavior that results in different types of behavior. For people living on the slope of Mt. Merapi, the types of behavior during the evacuation from the eruption of Mt. Merapi are divided into five categories: behavior of official leader, behavior of cultural leader, behavior of vulnerable groups, behavior of prepared community members and behavior of unprepared community members.

During an evacuation, people have to make a series of decisions, namely to evacuate or to stay, to choose a means of transportation and to choose a route. This study has explained the behavioral framework of each type of community for which each phase of the decision-making concerning the evacuation from the eruption of Mount Merapi is explained in detail. This behavioral framework explains behavioral rules that would later serve as aprimary component in agent-based computer simulation modeling.

RECOMMENDATIONS

Further research is needed to design a computer simulation program. The simulation will produce various scenarios in which the best scenario will be chosen to formulate a more comprehensive disaster evacuation planning.

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